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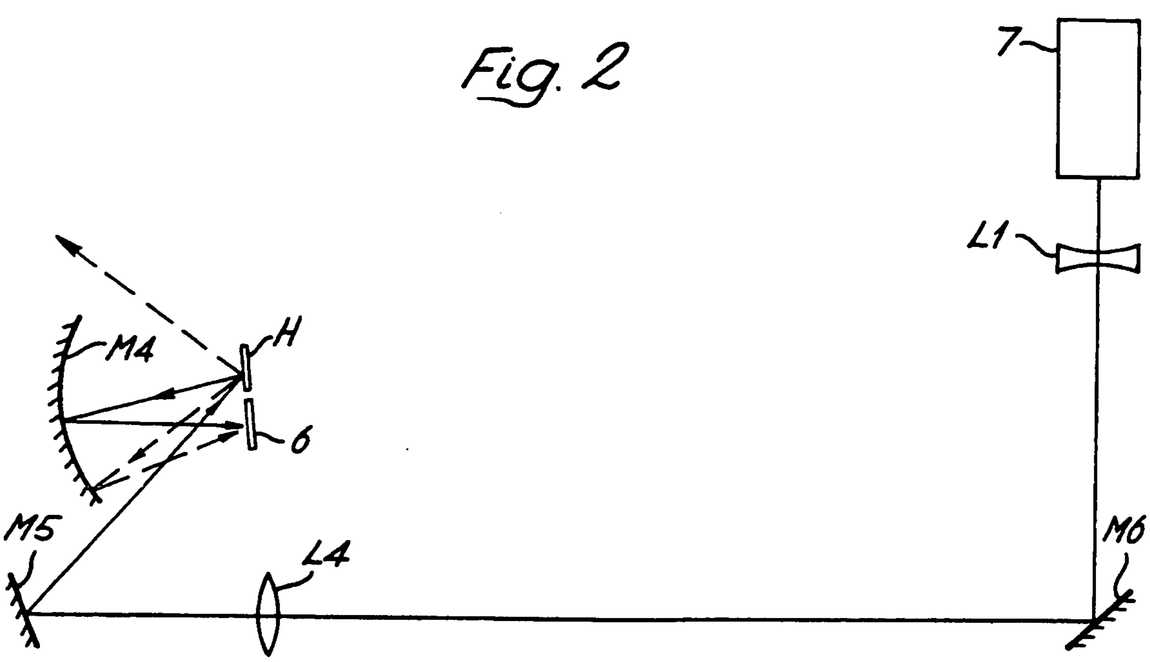
(54) Apparatus for the production of high resolution images

(57) Apparatus for the production of large area high resolution images of a holographic mask comprises an excimer laser (7) and beam expander (L1,L4,M6,M5) to direct a beam on to a reflection hologram (H) located near the image plane of the mask. The image of the mask is formed by reflection in a concave mirror (M4), and the reconstructed holographic image is formed at (6).

The invention is applied to the photolithographic method for the manufacture of integrated circuits.

Fig. 2



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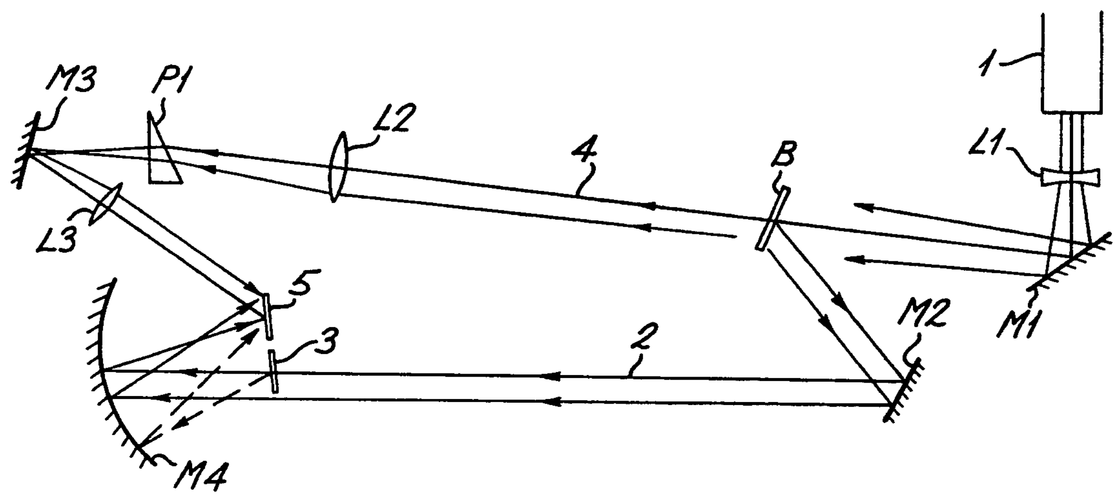

Fig. 1

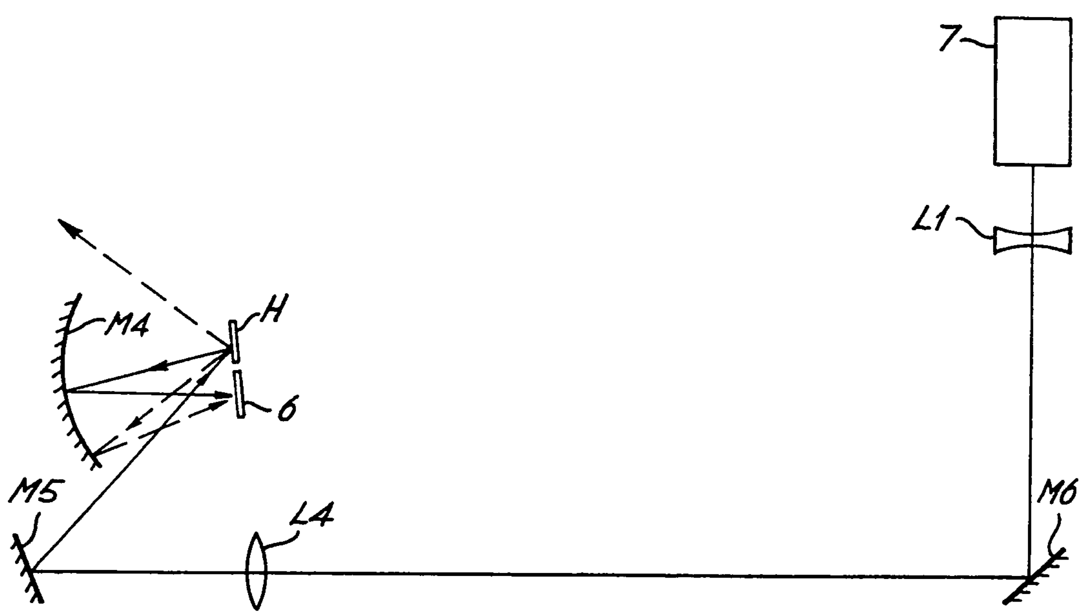

Fig. 2

SPECIFICATION

Meth d and apparatus for th production of high resoluti n images

This invention relates to methods and apparatus for the production of high resolution images. It finds particular application in photolithographic techniques used for the manufacture of integrated circuits.

In an endeavour to increase the handling speed of photolithographic apparatus used in the manufacture of integrated circuits, and also to increase their resolution thereby achieving higher component packing densities, rare gas halide lasers have been used in both contact and imaging printers (K. Jain and R.T. Keith, Applied Optics *23* 648 (1948). However, current throughputs are as much limited by step and repeat processes, whilst the resolution is as much limited by the characteristics of the imaging system as by the properties of the radiation used.

We have shown that both these limitations can be removed by using a holographic process which does not necessarily require high quality optics for high resolution and because of this there is no fundamental limitation on field size. In consequence the full resolution benefit of short wavelength excimer lasers can be realized and large areas, for example, the entire wafer area can be exposed at once, obviating the need for current time-wasting step and repeat techniques. Holography has potentially a number of other advantages. The correct image referencing is simpler since it is referenced into the same position as the original object (or mask) and the original mask position is not critical. Point defects or scratches accruing on the hologram are not important if the hologram is recorded in an out of focus plane of the object. The geometry is very flexible and can generally be adjusted to suit requirements or convenience. The numeral aperture of the holographic imaging system can easily be made very large giving a potential resolution equal to the wavelength (0.19 μm for the ArF laser).

According to the present invention there is provided apparatus for the production of high quality resolution images over large areas, comprising a source of radiation, a holographic recording of a radiation mask and means for reconstructing an image of said radiation mask in the vicinity of a predetermined surface in order selectively to illuminate said surface with said radiation.

The particular methods and apparatus proposed are in considerable part directed to alleviating the tolerances on source and geometry which would probably rule out holography as a feasible technique for microcircuit replication.

An embodiment of the invention will now be particularly described with refer nce to the accompanying drawings in which:—

Figure 1 is a diagram showing the production of a holographic recording of a radiation mask; and

Figure 2 is a similar diagram showing the arrangement of the holographic recording in apparatus for the reconstruction of an image of the radiation mask.

Referring now to Fig. 1 of the drawings, radiation from a krypton fluoride excimer laser 1 passes by way of a lens L1 and mirror M1 to a beam splitter B. An object beam 2 passes by way of a second mirror M2 through an object comprising a mask 3 usable for photolithographic processing of semiconductor devices and onto a holographic recording medium 5 by way of a focussing mirror M4. A reference beam 4 passes by way of a lens L2, a mirror M3 and a further lens L3 to form together with the object beam 2 a holographic recording on a recording medium 5 in a plane adjacent to the mask.

Reconstruction of the holographic image 6 is performed by radiation from an excimer laser 7 which passes by way of a beam expander (L, and L4) and two mirrors M5, M6 to the hologram H which has been processed to reconstruct with high efficiency in reflection. The image of the photolithographic mask is formed by reflection in a concave mirror M4.

The hologram is located near the image plane of the mask. With this arrangement the coherence requirements in recording and reconstruction, geometrical requirements on the reconstructing beam, and the requirements on optical quality of the hologram medium and substrate are reduced and become simple to satisfy. Further, using the extra optics (L_2, L_3 and P.) shown in the recording reference beam (Fig. 1) the spatial coherence of the recording beams need not be high since both reference and object beams are spatially matched at the hologram plane. This spatial matching of the beams minimises the requirement on the mechanical stability of all optical components before the beam splitter. The hologram is recorded close to the image plane but sufficiently far from it to reduce the effect in reconstruction of defects in the hologram plane.

The object beam at the hologram plane is entirely 'specular'; that is to say it has no scattered components and consists only of a flat or spherical wavefront transmitted and diffracted by the mask. The reconstruction from the hologram so produced is not illuminated by random phase components as would be the case for a scattered light hologram and hence does not show image speckle which would prevent the attainment of adequate uniformity and resolution for microcircuit replication. It is important to eliminate all sources of scatter both in recording and reconstruction as these will give a background speckle pattern in the image plane.

The recording geometry was selected for

being simple, inexpensive and achromatic. The mirror is used with a NA 0.24 giving potentially sub-micron resolution at a wavelength of 249 nm.

The imaging mirror may be used at 1:1 magnification to keep down the holographic exposure, and minimise the mirror imaging aberrations. The technique might be modified usefully for higher magnification to reduce the resolution requirement of the hologram and to reduce the intensity on the hologram in the reconstructing stage. The latter may be essential if the hologram is to be used for photoablation lithography with short pulse excimer lasers as this requires high single pulse energies.

For reference and object beam with matched path length at the centre of the hologram, the coherence length requirement in recording is $\sim\frac{1}{2}$ d $\sin\theta$ where d=width of hologram and θ=angle between object and reference beam. For a 4 inch wafer and hologram the maximum requirement on coherence length ($\theta\sim90°$) would be 5 cm corresponding to a laser bandwith of less than 0.2 cm^{-1}. It is straightforward to achieve this linewidth with excimer lasers.

Holograms were recorded in Shipley photoresist type AZ2415. Recent developments have shown this material to be well fitted to recording high resolution, efficient, scatter free holograms at excimer laser wavelengths. Other materials are possible but photoresist, being a 'surface relief' hologram, can also be reflection coated for high efficiency and replicated onto more robust material.

Repositioning of the hologram after processing can be achieved simply and to adequate accuracy by interferometry. The hologram is replaced in the original recording arrangement thus giving rise to two 'object' beams, the original beam from the object and a beam reconstructed by the hologram from the original reference beam. The 'object' beams give a two beam interference pattern which shows the departure of the hologram from its correct position.

The excimer laser used in this embodiment was a commercial pulsed KrF laser operating at a wavelength 249 nm and line narrowed to $\approx$0.3 cm^{-1} and had a beam divergence less than 100 μrad. The holograms were recorded using a single laser pulse of duration 20 ms and with an exposure of $\sim$19mJ/cm^2 on the photoresist. Reference to object beam intensity ratio is not critical and had a value of 4:1.

The developed hologram was coated with aluminium by evaporation and replaced for reconstruction. The reconstructed image was obtained by reversing the optical process, as already indicated, and recorded on a photoresist-coated plate placed in the exact position of the original mask. The photoresist was given an exposure (approximately 50mJ/cm^2) to enable development which totally removed the resist in exposed areas as would be required in microcircuit replication.

Resolution tests of a line and dot pattern chart with elements down to 1 μm in dimension showed errors in edge positions and linewidths to be well under 1 μm. and close to the diffraction limit of this particular embodiment.

Exposure levels indicate that even with a modest holographic reconstruction efficiency of say 20% total laser energy to expose a complete 10 cm$\times$10 cm wafer would be approximately 50J. With current commercial models a complete wafer exposure time of 1 S is feasible.

A broadband laser can be used in reconstruction since coherence is only required across the area of hologram contributing to each point in the reconstructed image. Since the holoram is recorded close to an image plane this area is small, perhaps only of millimetre size. A test of this feature of the design showed a degradation of resolution to 2 μm while using the total bandwith (50 cm^{-1}) of the KrF excimer laser.

A necessary part of the process of microcircuit replication requires accurate referencing of the wafer to achieve good image fidelity and precise relative positioning of sequential circuit layers. The holographic technique does not require accurate repositioning of the hologram so long as the wafer can be accurately positioned in the image plane. Fiducial marks on microcircuit masks and common to all masks will be reconstructed by the holographic process and may be used for referencing as in current commercial machines. However a further holographic design feature is proposed which may be used to assist the image referencing. A secondary hologram of all or just special features of the mask is recorded at the same time as the main mask hologram on the same resist surface without disturbing the geometry. This secondary hologram may be either superimposed onto the main hologram or alongside it as required, and it may be recorded at a longer wavelength, perhaps in the visible, to optimise the convenience and speed of the referencing process.

The narrowest linewidth observed ('1 μm' line) was about 1.5 μm, comparing well with the diffraction limited linewidth, for a 0.24NA system at 633 nm, of approximately 1.5 μm (1/e intensity points).

A hologram of an area of mask of diameter 35 mm showed that, as expected, the resolution can be maintained over large object fields and in regions where the mirror imaging has large aberrations.

For KrF holography a resolution of 1 μm can be achieved. Use of a shorter wavelength improves resolution but not to an extent expected by reduction in wavelengths. This limit on resolution as the limit can be explained as being imposed by the grain size or the photographic emulsion together with the limited

resolution of ur UV microscope.

Speckle noise resulting from scatter in the photographic emulsion is seen to be considerably worse at the shorter wavelength and this also affects the observed resolution to some extent.

The reconstructing efficiency was greatly improved by depositing a layer of aluminium onto the hologram by thermal evaporation.

The reconstructed image fidelity was not affected by increasing the linewidth of the reconstructing beam from 0.1 cm^{-1} to 50 cm^{-1}, and was only slightly affected (resolution $\sim$2 μm) by reducing the transverse coherence from single transverse mode to 5–10×diffraction limit. These are particular advantages of the near focal plane geometry used and enable simple and powerful lasers to be used in reconstruction if desired.

We achieved 1 μm resolution in the holographic reconstruction of a resolution mask using a wavelength of 249nm from a pulsed KrF excimer laser. The main limitation in the process used resulted from background speckle (not image speckle) due to grain scatter in the photographic emulsion and this limited both the resolution and the signal to noise ratio. With the use of photoresist as the recording medium this limitation can be eliminated and a resolution below 0.5 m can be achieved. A further improvement is expected if an ArF laser operating at a wavelength of 193 nm is used and in this case it may be possible to record the hologram by photoablation and hence eliminate the development process.

Further modifications may also be made, e.g.

(i) high efficiencies with good fidelity can be achieved by aluminising the hologram and operating in reflection.

(ii) large area masks can be recorded without loss in fidelity.

(iii) geometries such as the one used enable the use of comparatively unsophisticated lasers and allow reasonable tolerances in the optical quality of the hologram surface and in the reconstruction geometry.

CLAIMS

1. Apparatus for the production of high quality resolution images over large areas, comprising a source of radiation, a holographic recording of a radiation mask and means for reconstructing an image of said radiation mask in the vicinity of a predetermined surface in order selectively to illuminate said surface with said radiation.

2. Apparatus for the production of high quality resolution images over large areas as claimed in Claim 1 wherein the source of radiation is a broad band laser.

3. Apparatus for the production of high quality resolution images as claimed in Claim 2 wherein the laser is an inert gas-halogen excimer laser.

4. Apparatus for the production of high quality resolution images as claimed in Claim 3 wherein the laser is a krypton-fluorine excimer laser.

5. Apparatus for the production of high quality resolution images as claimed in Claim 3 wherein the laser is an argon-fluorine laser.

6. Apparatus for the production of high quality resolution images as claimed in any one of the preceding claims wherein said holographic radiation mask comprises a hologram recorded close to the image plane, but spaced therefrom in order to reduce the effect of optical reconstruction of defects.

7. Apparatus for the production of high quality images as claimed in Claim 6 wherein said hologram is recorded in photo resist.

8. Apparatus for the production of high quality images as claimed in Claim 7 further including a reflective layer deposited on said hologram.

9. Apparatus for the production of high quality images as claimed in Claim 8 wherein said reflective layer is of aluminium.

10. Apparatus for the production of high quality images as claimed in any one of the preceding claims wherein said holographic recording incorporates a secondary hologram for alignment purposes.

11. Apparatus for the production of high quality images substantially as herein described with reference to and as shown in the accompanying drawings.

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